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Display of Holograms in White Light

By C. B. BURCKHARDT

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This paper describes a new method for displaying holograms in white light. The method gives reasonably good reconstructions although certain image defects are inherent in the method. It differs from previously reported methods of white light reconstruction[1,2] in that the whole spectrum is used for reconstruction and therefore black and white reconstructions can be obtained. The method does not depend on the volume properties of the photographic emulsion.

The basic arrangement is shown in Fig. 1. The white light illuminates a hologram which had been formed with a plane off-axis reference beam.[3] Behind the hologram there is a Venetian blind structure which blocks off the direct light but lets through the diffracted beam. The diffracted beam is diffracted a second time at a plane transmission grating which can be formed photographically with two plane beams. The angle between the two beams which form the plane grating has to be equal to the mean angle between the subject beam and reference beam used to form the hologram.

The reconstruction resulting from the configuration of Fig. 1 will now be explained. Intuitively, one can say that there is a large color dispersion at the first hologram because it can be considered a high spatial frequency diffraction grating. Since the light is diffracted in the opposite direction by the second grating this color dispersion is compensated. In order to be more quantitative, assume that during the formation of the hologram the subject beam A_s on the photographic plate is given by

$$A_s = a(x,y) \exp (j\omega_s x), \tag{1}$$

where ω_s is the mean radian frequency of the subject beam and the center of the spatial frequency spectrum of $a(x,y)$ is at zero. Assume that the reference beam R is given by

$$R = B \exp (-j\omega_r x), \tag{2}$$

where B is the amplitude and $-\omega_r$ is the radian frequency of the reference beam. The photographic plate will record the intensity[3] and for the virtual image term we obtain

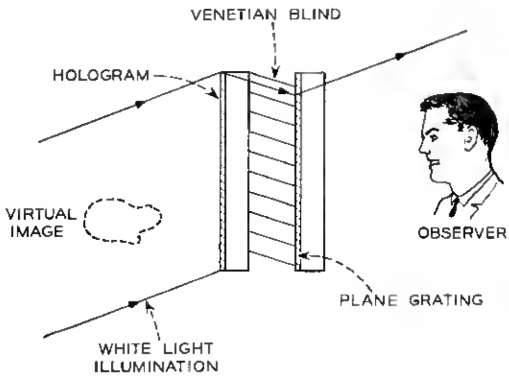

Fig. 1 — White light display of a hologram.

$$A_s \cdot R^* = a(x,y)B \exp (j[\omega_s + \omega_r]x), \tag{3}$$

where the star means complex conjugate.

The plane grating is formed by two plane wave beams which can be expressed as $G \exp (j\omega_s x)$ and $G \exp (-j\omega_r x)$ and for the intensity $\chi\chi^*$ on the plate we will obtain

$$\chi\chi^* = 2G^2 + G^2 \exp (j[\omega_s + \omega_r]x) + G^2 \exp (-j[\omega_s + \omega_r]x). \tag{4}$$

We now assume that the two plates are developed in such a way tbat their amplitude transmittance is proportional to the intensity during exposure. Since the hologram and the plane grating are spaced only a short distance behind one another, to get the amplitude transmittance corresponding to the virtual image we can multiply the amplitude transmittance of the bologram, $A_s \cdot R^*$, with that of the plane grating $\chi\chi^*$. We are now interested in tbe term which is given by the product of (3) with the last term of (4). This product,

$$a(x,y)BG^2, \tag{5}$$

is equal to the subject beam term, (1), translated to a center frequency of zero. This term, therefore, represents the reconstruction of a virtual image in the directiou of the illuminating beam. It is possible to make a single hologram where the virtual image term has the form of (5). One chooses a subject beam as given in (1) and a reference beam $B \exp (j\omega_s x)$, i.e., the reference beam has the same mean direction as the subject beam. This is the on-axis hologram which has the well-known disadvantage that the direct beam, the real image, and the virtual image fall onto each other. The configuration of Fig. 1 does not have this disadvantage, witb respect

to the virtual image; it is, however, in a sense "equivalent" to the on-axis hologram. Therefore, the following explanations will be in terms of the equivalent on-axis hologram.

In the on-axis hologram each object point forms its own on-axis Fresnel zone plate on the photographic plate. Upon illumination each zone plate forms a divergent spherical wavefront and therefore, a virtual image point. Since the focal length of the zone plate is inversely proportional to the wavelength of the illuminating light, the virtual image points for the different colors are staggered in depth. It is important to note that one does not perceive this difference in depth if one looks at the virtual image point through the center of its zone plate and if the eye has sufficient depth of field as is usually the case. For a particular point of observation, a region of image points will be approximately "on-axis" and this region will be in sharpest focus and have minimum color. As the eye is moved different regions of image points will come into sharpest focus.

It is possible to use to advantage a spherically converging reference and illuminating beam of the same curvature. A little thought will show that by placing the eye at the focal point of the reference beam one can look at all the virtual image points through the centers of their respective zone plates. From this point one therefore sees an image which could be called "quasi-achromatic". (This can also be shown by using imaging formulas.[4] They show that for the point mentioned, the ratio between the eye-to-image-point distance and lateral image magnification is independent of wavelength.) If one moves the eye away from this point the image starts to blur.

Experimentally, it was found that the best reconstructions were obtained by using a slightly convergent reference beam and viewing the reconstruction from a point in front of the focus of the reference beam. This is probably so, because one then has more tolerance with respect to movement of the eye.

It is, of course, possible to place the plane grating in front of the hologram in the configuration of Fig. 1. Particularly bright reconstructions are obtained by using the first diffracted order of a blazed reflection grating for illuminating the hologram. The reconstruction can then be easily viewed against a background of ordinary room light.

Fig. 2 shows a photograph of the virtual image of a white light reconstruction. The lens used to form a convergent reference and illuminating beam has a focal length of 48 cm and was placed 18 cm in front of the hologram plate. The image-forming photographic lens was placed at the focal point of the reference lens where the image is quasi-

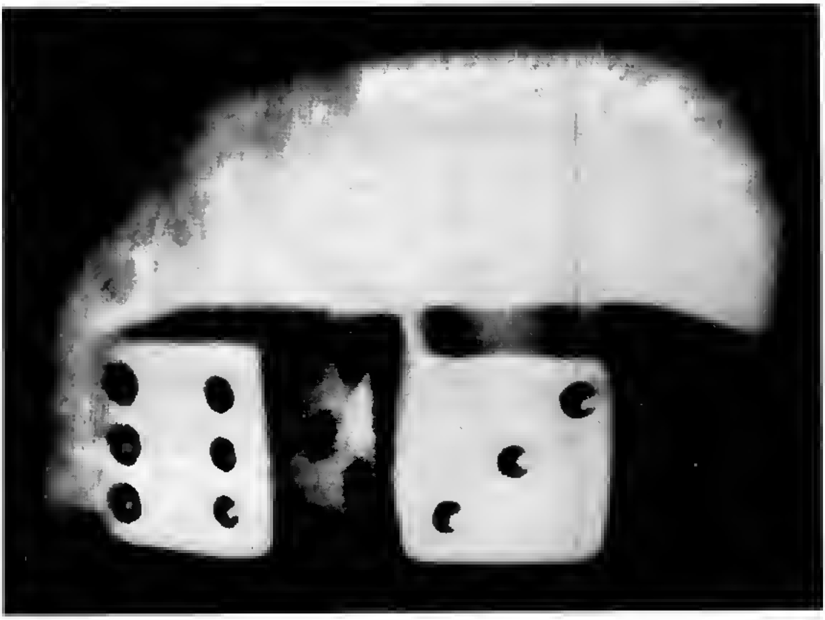

Fig. 2 — Photograph of the virtual image with the image-forming lens at the quasi-achromatic point.

achromatic. The photographic lens had an aperture of 6.5 mm and a focal length of 17 cm. The distance between subject and plate during the formation of the hologram was 18 cm and the angle between the subject beam and reference beam was 22°. The angle between the two plane beams used to form the photographic grating was also 22°. The Venetian blind structure is not visible in Fig. 2 because it was out of focus. A zirconium arc lamp was used as white light source.

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REFERENCES

1. Stroke, G. W. and Labeyrie, A. E., White-Light Reconstruction of Holographic Images Using the Lippman-Bragg Diffraction Effect, Phys. Letters, *20*, March, 1966, 368–370.
2. Lin, L. H., Pennington, K. S., Stroke, G. W., and Labeyrie, A. E., Multicolor Holographic Image Reconstruction with White-Light Illumination, B.S.T.J., *45*, April, 1966, pp. 659–661.
3. Leith, E. N. and Upatnieks, J., Wavefront Reconstruction with Continuous-Tone Objects, J. Opt. Soc. Amer., *53*, December, 1963, pp. 1377–1381.
4. Meier, R. W., Magnification and Third-Order Aberrations in Holography, J. Opt. Soc. Amer., *55*, August, 1965, pp. 987–992.